Studies of the transitions between Geant4 hadronic models

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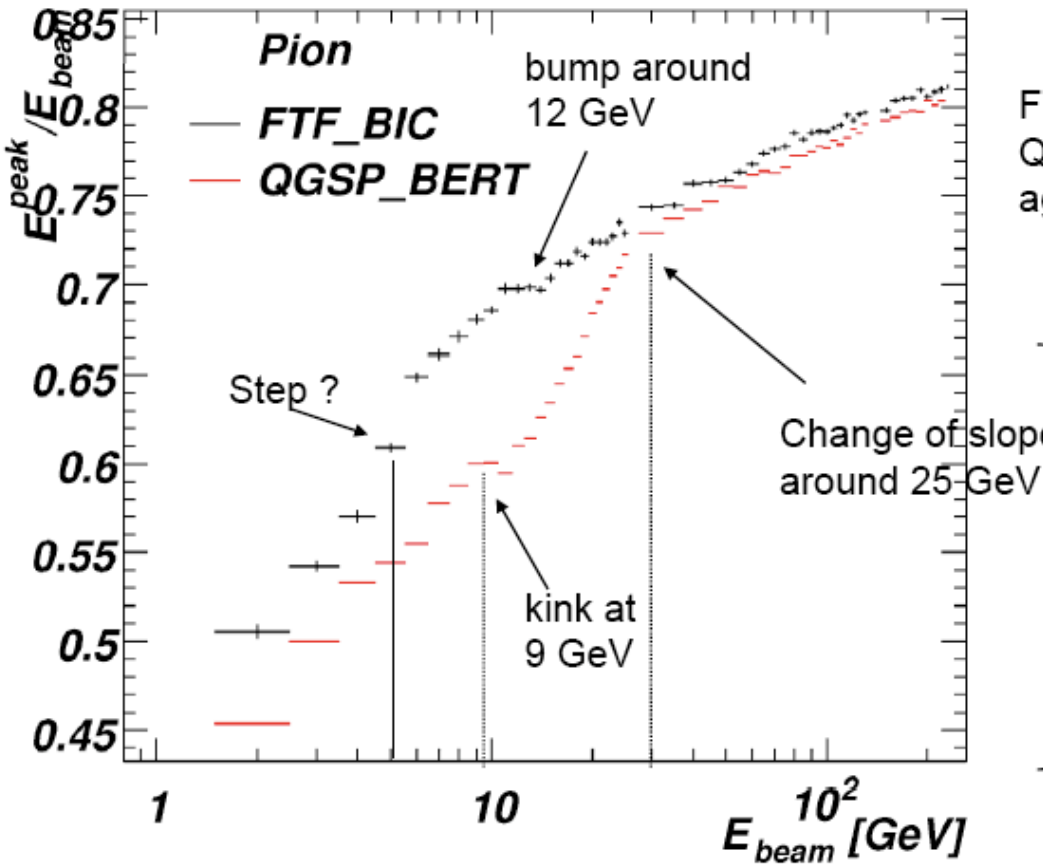
The problem

- CMS has found that in the Geant4 simulations of its calorimeter test-beam set-up, the energy response as a function of beam energy presents some unphysical discontinuities
- ATLAS has then found the same behavior in their calorimeter test-beam set-ups, and also for other observables, like energy resolution vs. beam energy
- This is a worrisome feature, because jets at LHC are made up of hadrons of quite different energies, so it can potential affect several analyses, and any simulation-based jet-calibration scheme…
- The reason for these unphysical discontinuties is quite obvious: the transition between hadronic models. However, it is not trivial to fix it…

Energy response vs. beam energy

Problem of matching models:

ATLAS Tile



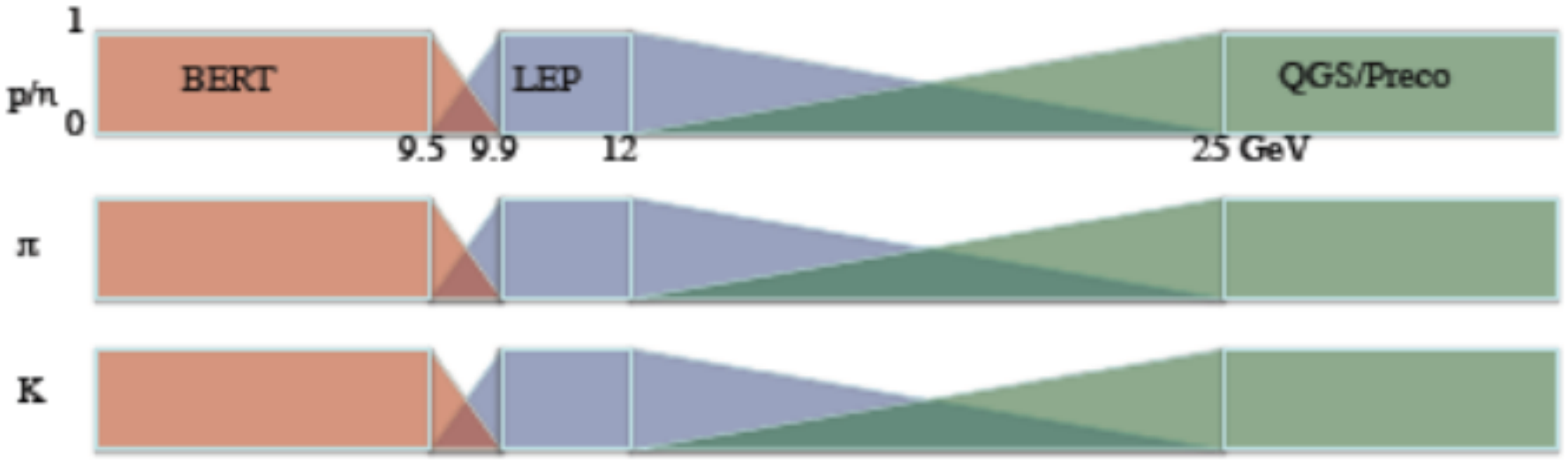
FTF_BIC is more smooth
QGSP_BERT is in better agreement to data

Effect of transition between models ?

QGSP_BERT:
- 0-9.9 GeV Bertini intra-nuclear cascade (BERT)
- 9.5-25 GeV low energy parameterised model (LEP)
- >12 GeV QGSP

FTF_BIC:
- 0-5 GeV binary cascade model (BIC)
- 0-5 GeV LEP for capture and fission processes
- >5 GeV Fritiof model (FTF)

QGSP_BERT Physics List



General problem of transition between:

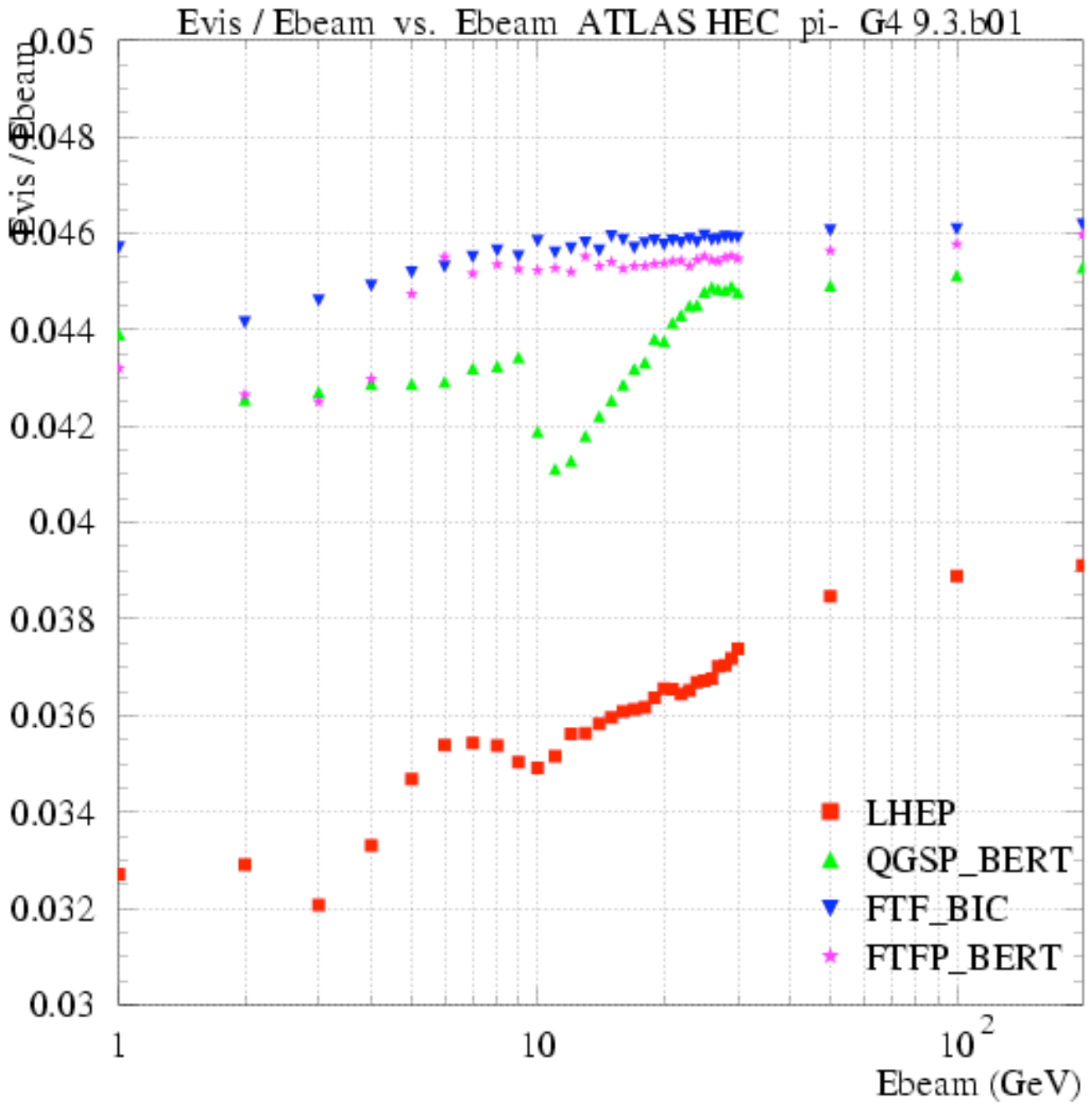
- High-energy : string models
- Intermediate/low energy : cascade models

Road-map

- Reproduce the problem with simplified calorimeter
- Compare different Physics Lists
- Understand the differences between models at microscopic level (i.e. thin-target, model-level)
- Improve the mixing between hadronic models in Physics Lists by:

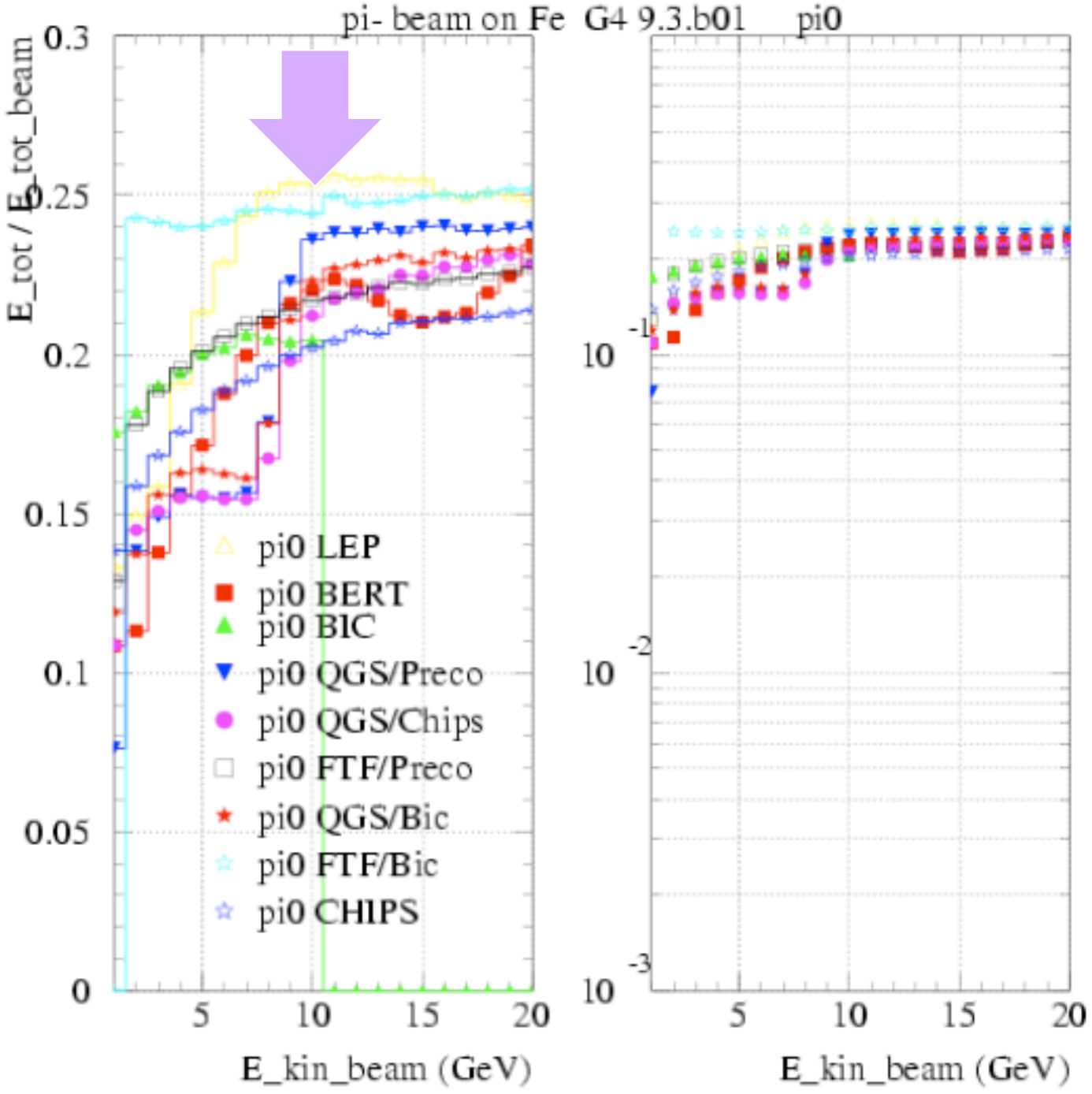
  1. Changing the transition regions between models in existing Physics Lists
  2. Creating novel mixtures of models in new Physics Lists
  3. Improving the hadronic models themselves

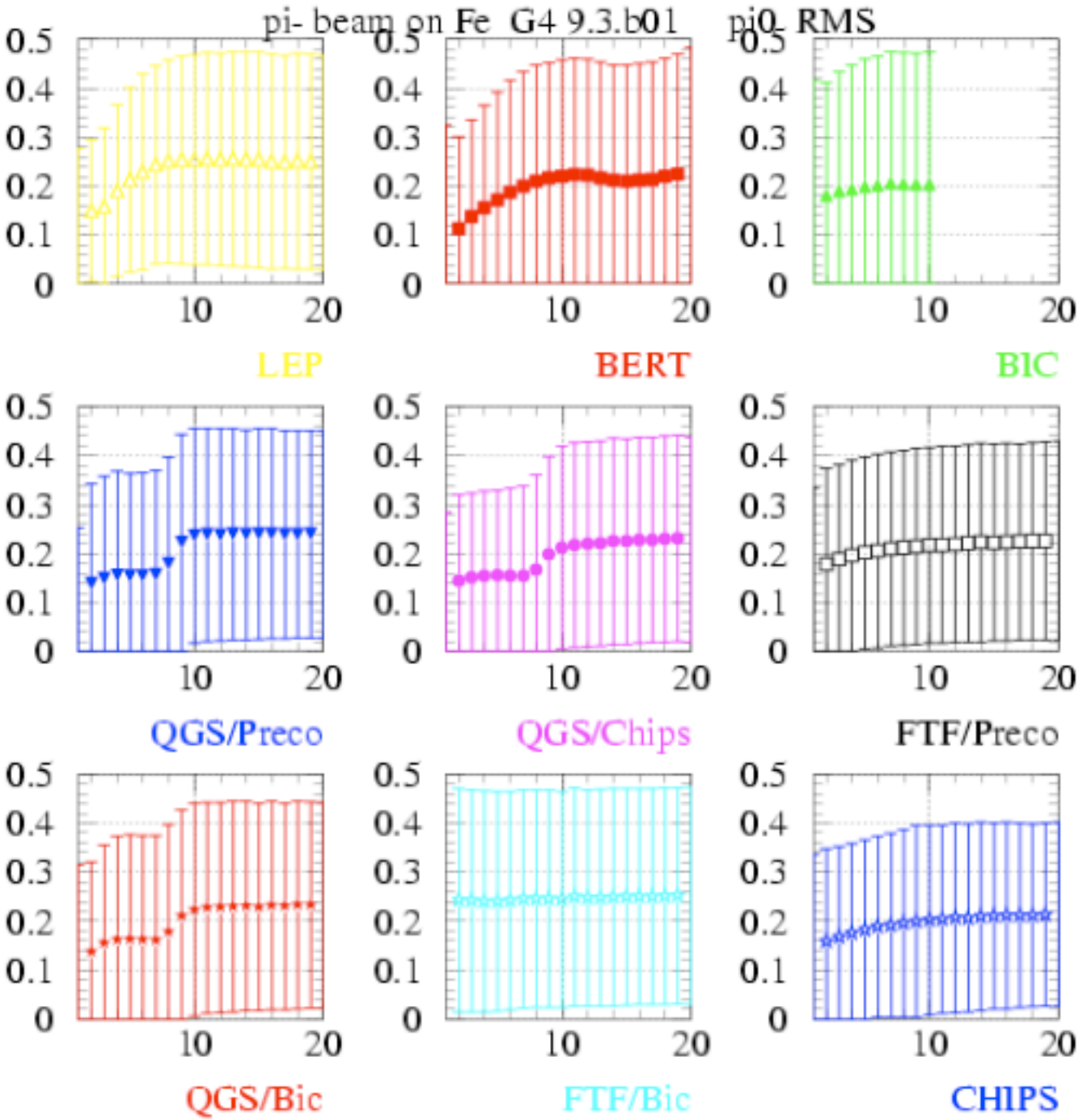
Energy response in a simplified **Cu-LAr** calorimeter

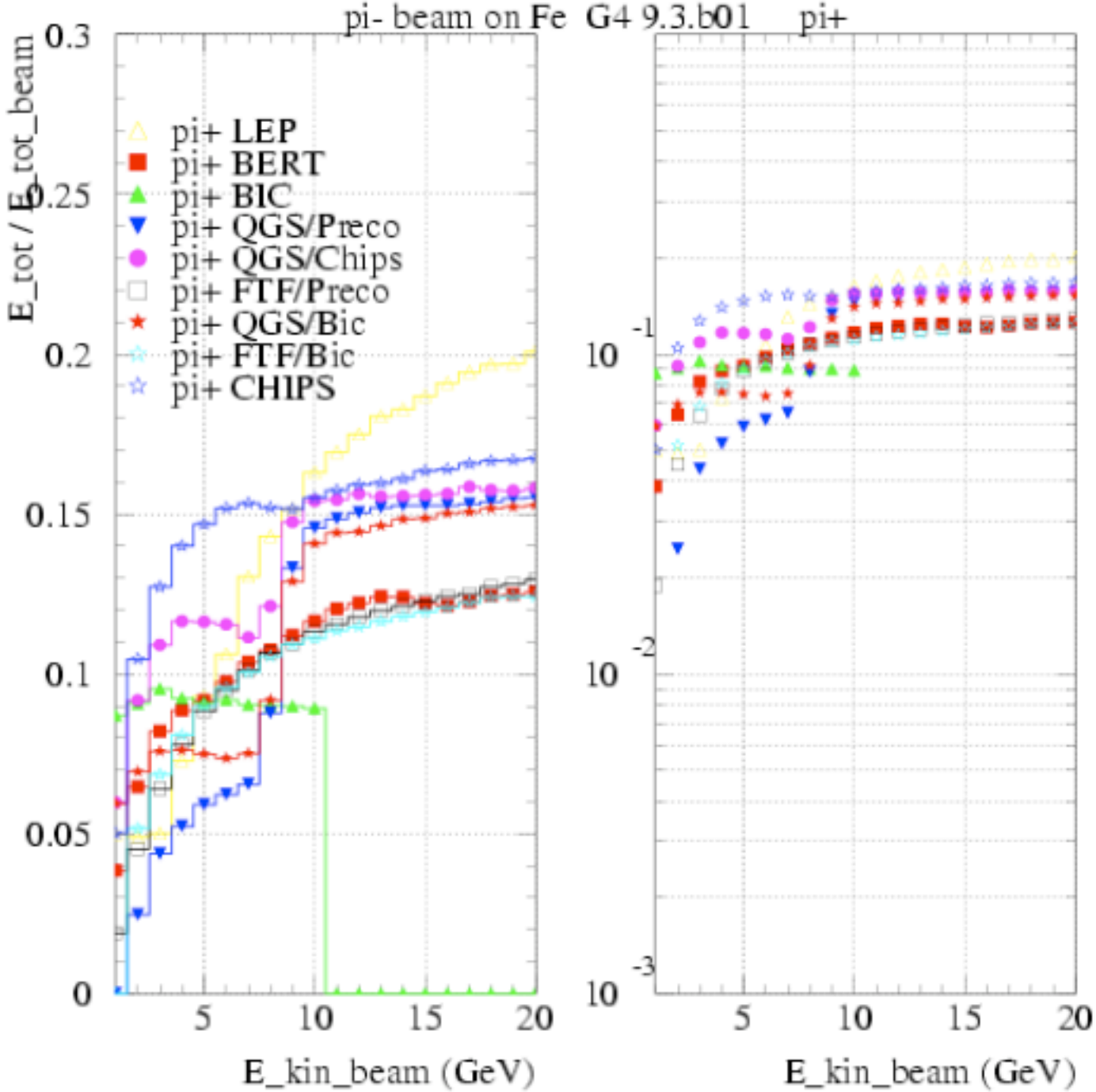


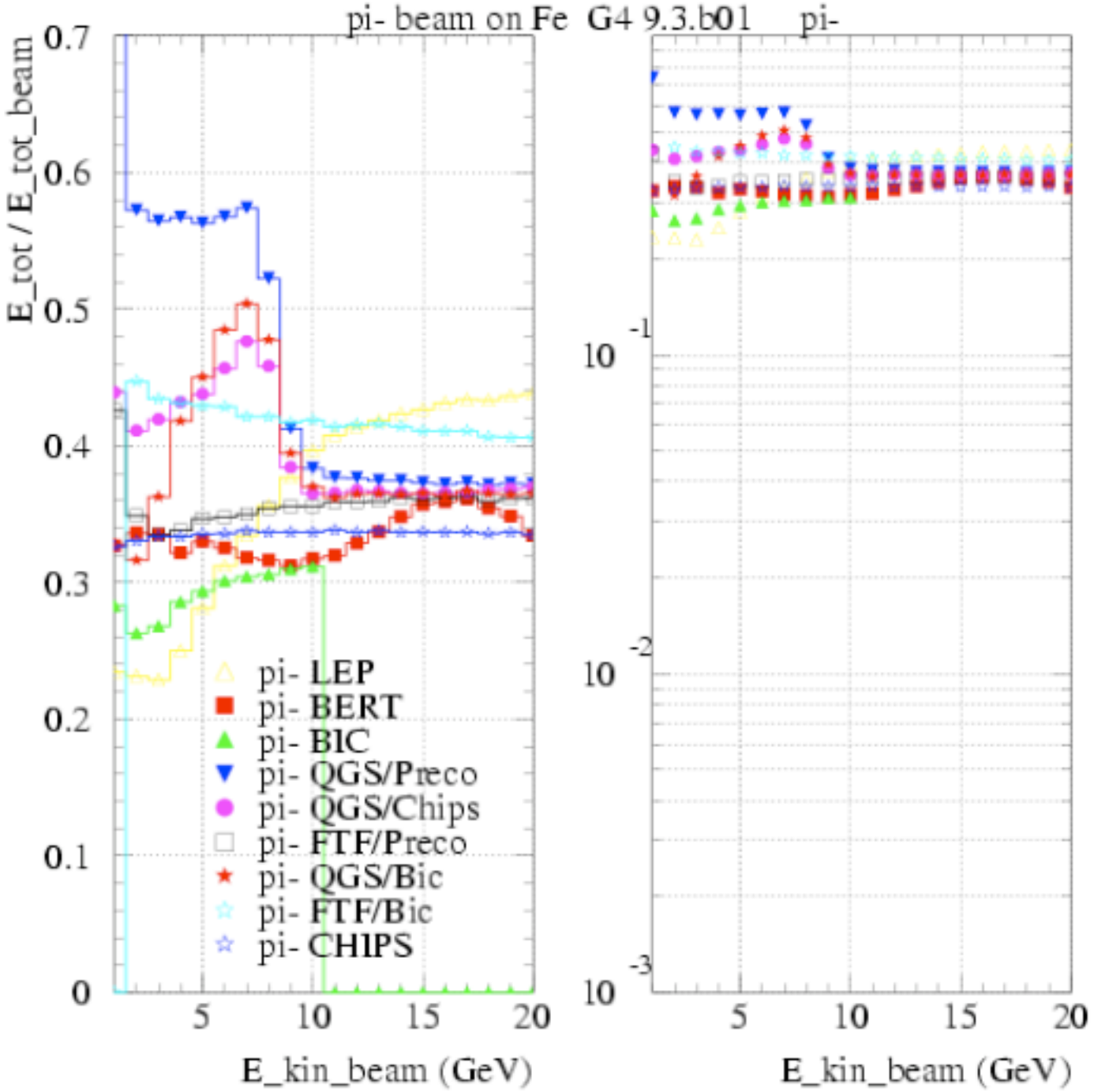
Model-level results

- Geant4 9.3.b01
- Beam particle: **pi-** (p, n, k, pbar)
  beam kinetic energies: **1 - 20 GeV**
  target material: **Iron** (Pb)
- Model-level only (not Physics Lists)
- 50,000 events (i.e. interactions) simulated for each considered case
- Main variables considered:
  - Average sum of total energies of **pi-** , **pi+** , **pi0**
  - Average sum of kinetic energies of **p** , **n** , light **ions** (d,t,He)
  - Average total energy
  - Ratios: n/p (backward-going), 2*pi0/(pi+ + pi-)
  - RMS of the above variables

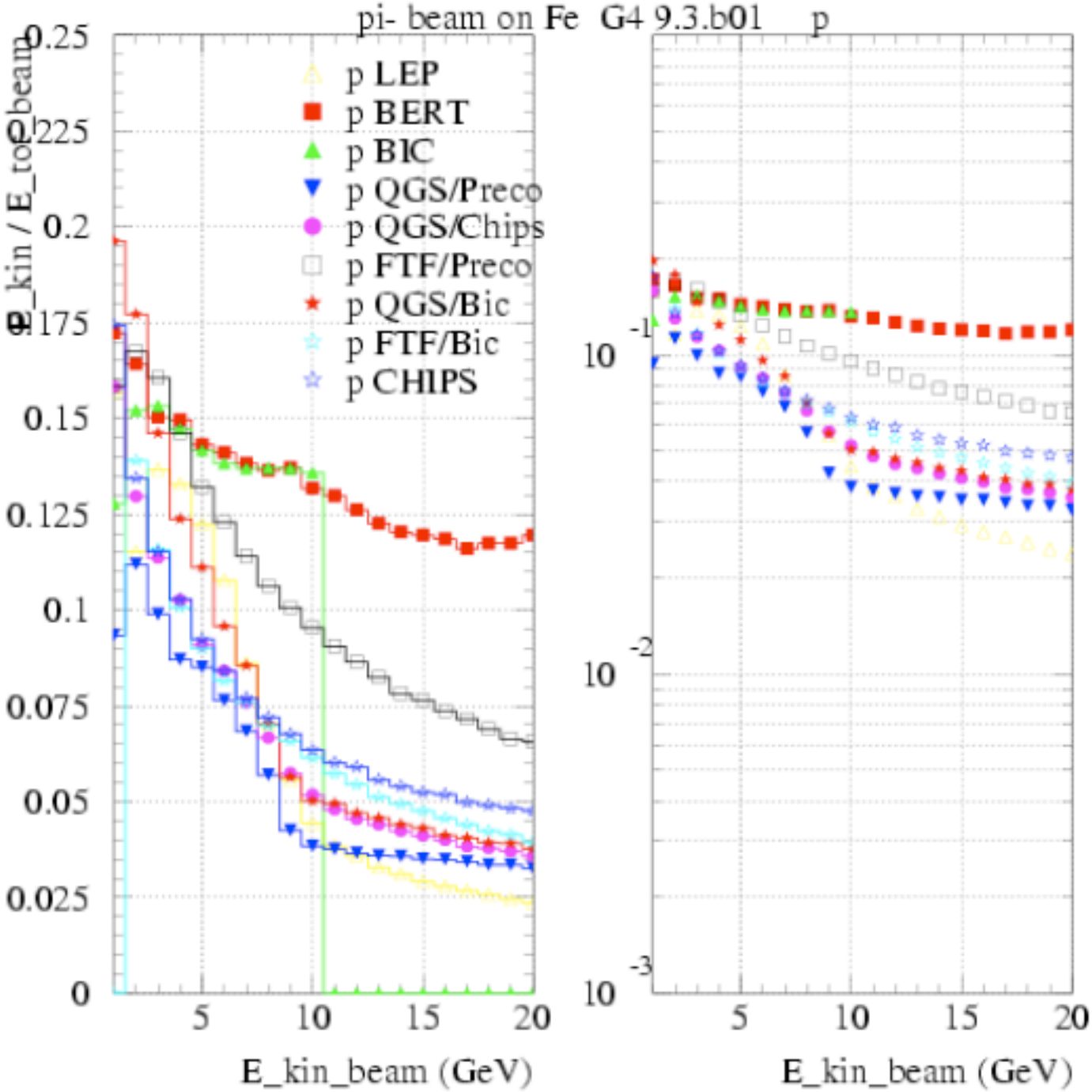

pi- beam on Fe G4 9.3.b01 pi0
E_tot / E_tot_beam
0.3
0.25
0.2
0.15
0.1
0.05
0
pi0 LEP
pi0 BERT
pi0 BIC
pi0 QGS/Preco
pi0 QGS/Chips
pi0 FTF/Preco
pi0 QGS/Bic
pi0 FTF/Bic
pi0 CHIPS
5
10
15
20
E_kin_beam (GeV)
10
-1
10
-2
10
-3
5
10
15
20
E_kin_beam (GeV)


pi- beam on Fe G4 9.3.b01
pi0 RMS
0.5
0.4
0.3
0.2
0.1
0
10
20
LEP
BERT
BIC
QGS/Preco
QGS/Chips
FTF/Preco
QGS/Bic
FTF/Bic
CHIPS

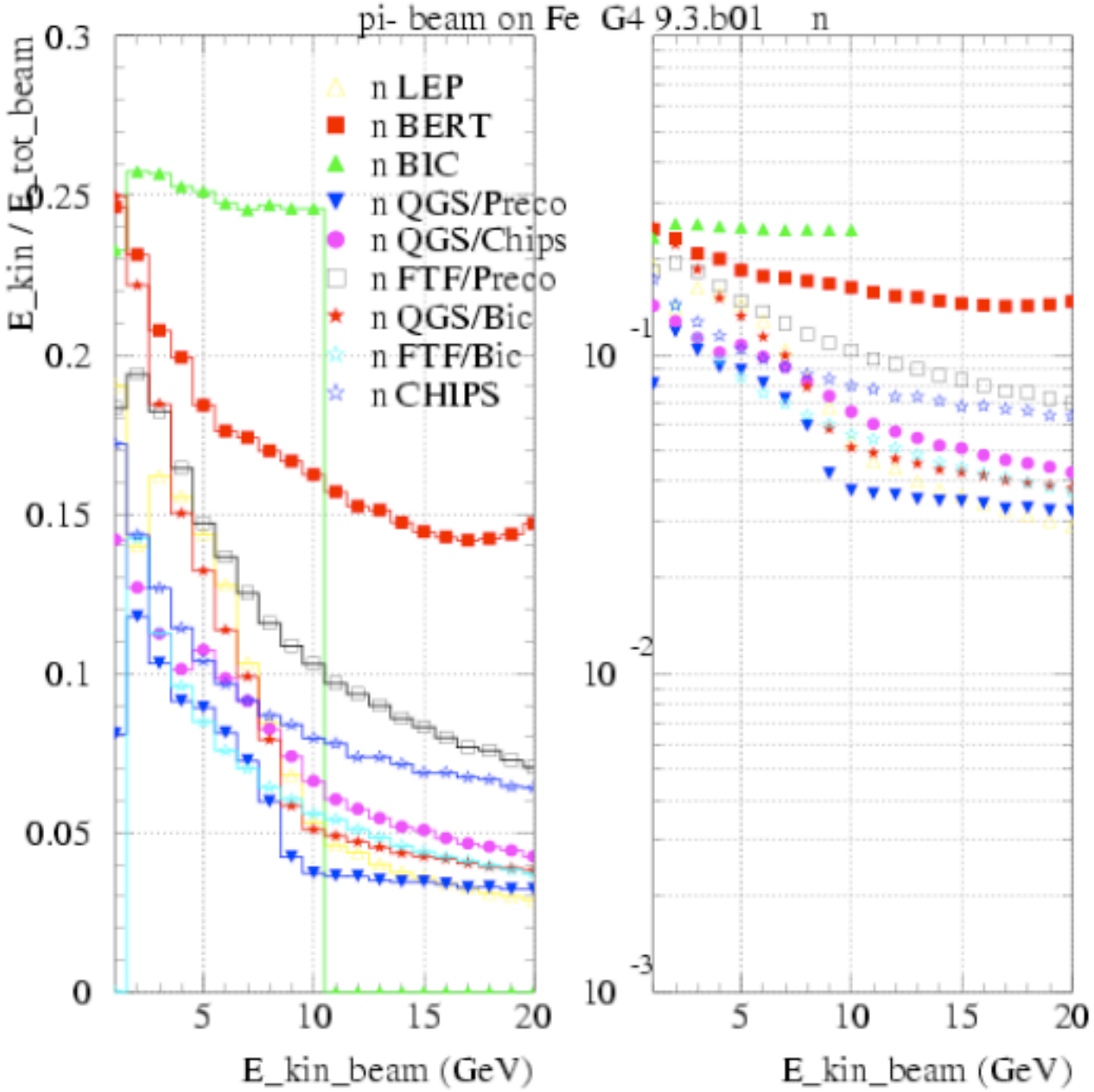

pi- beam on Fe G4 9.3.b01 pi+
E_tot / E_tot_beam
pi+ LEP
pi+ BERT
pi+ BIC
pi+ QGS/Preco
pi+ QGS/Chips
pi+ FTF/Preco
pi+ QGS/Bic
pi+ FTF/Bic
pi+ CHIPS
0.3
0.25
0.2
0.15
0.1
0.05
0
5
10
15
20
E_kin_beam (GeV)
10^-1
10^-2
10^-3
5
10
15
20
E_kin_beam (GeV)

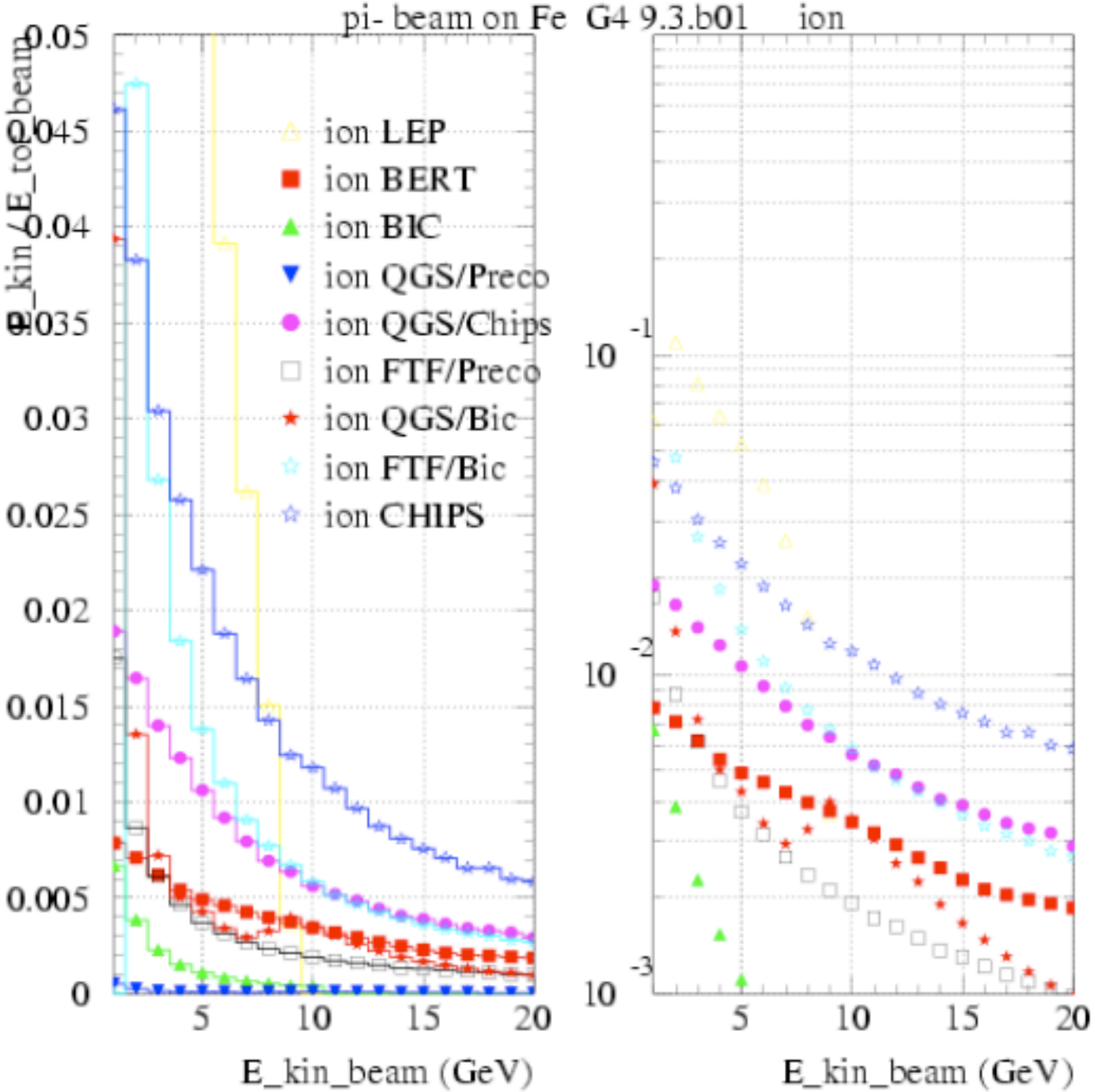

pi- beam on Fe G4 9.3.b01
pi-
E_tot / E_tot_beam
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5
10
15
20
E_kin_beam (GeV)
pi- LEP
pi- BERT
pi- BIC
pi- QGS/Preco
pi- QGS/Chips
pi- FTF/Preco
pi- QGS/Bic
pi- FTF/Bic
pi- CHIPS
10^-1
10^-2
10^-3
5
10
15
20
E_kin_beam (GeV)

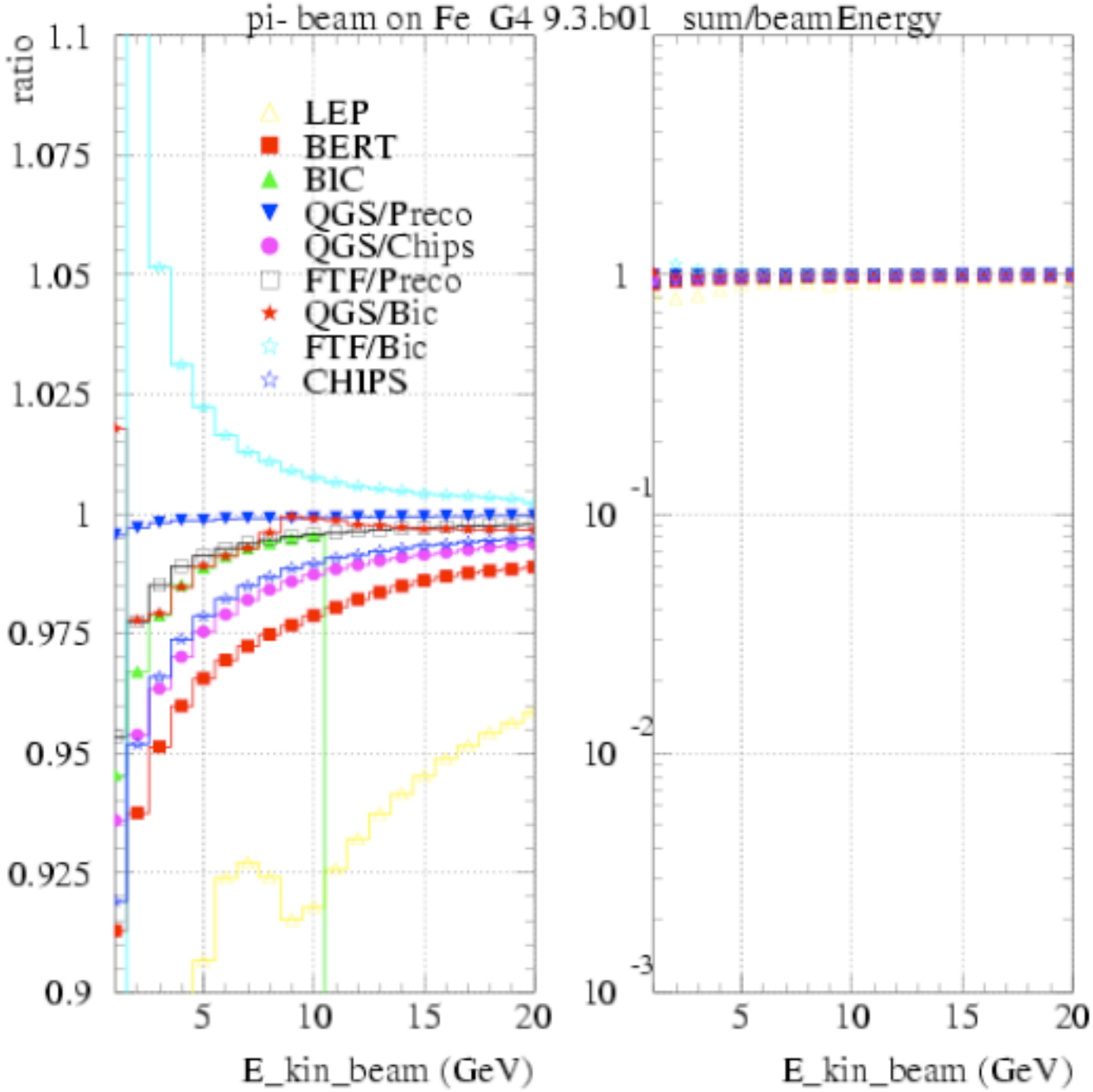
Too much energy into protons for Cascade models (BERT, BIC) for $E_{kin} \geq 5GeV$

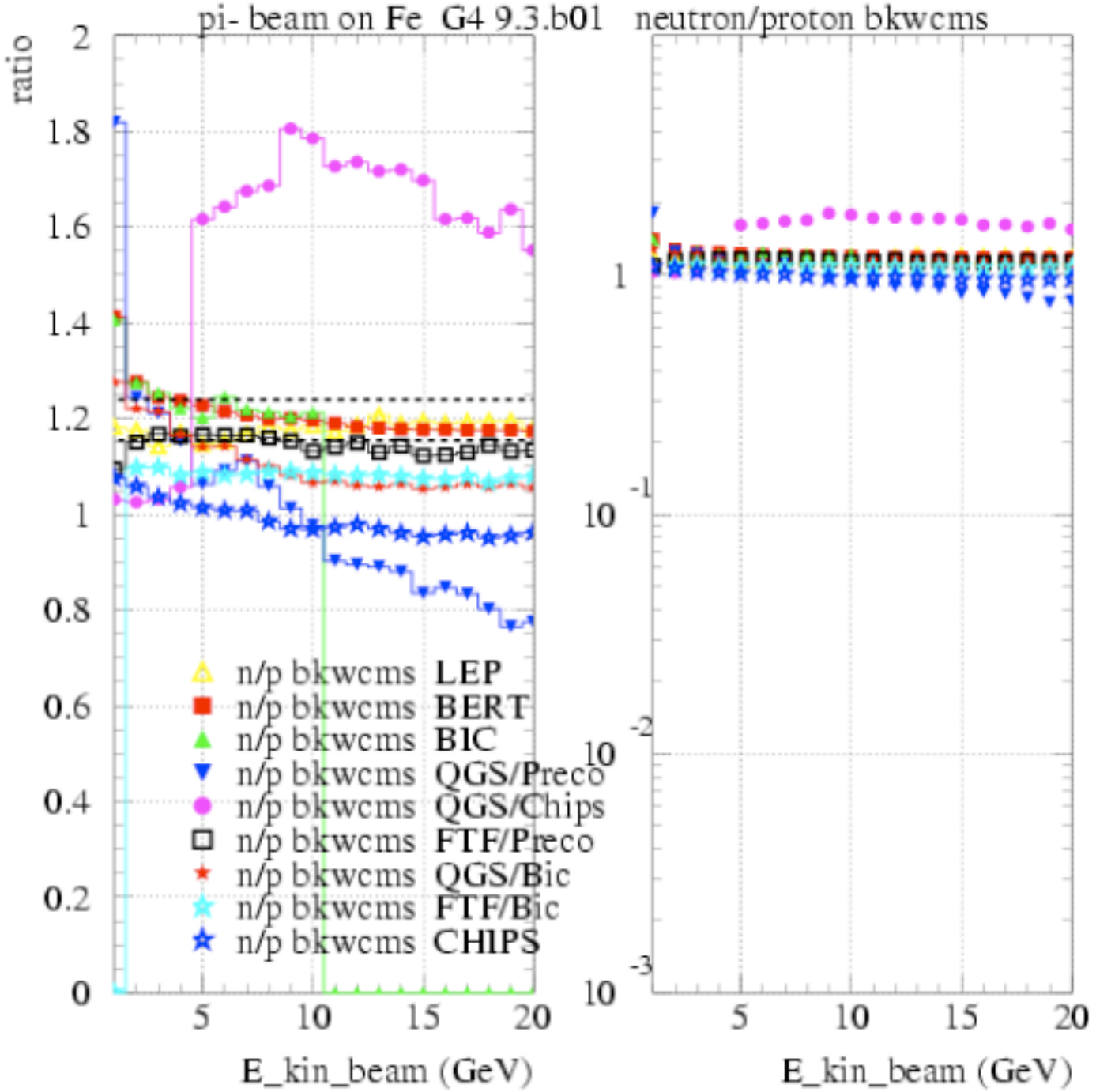


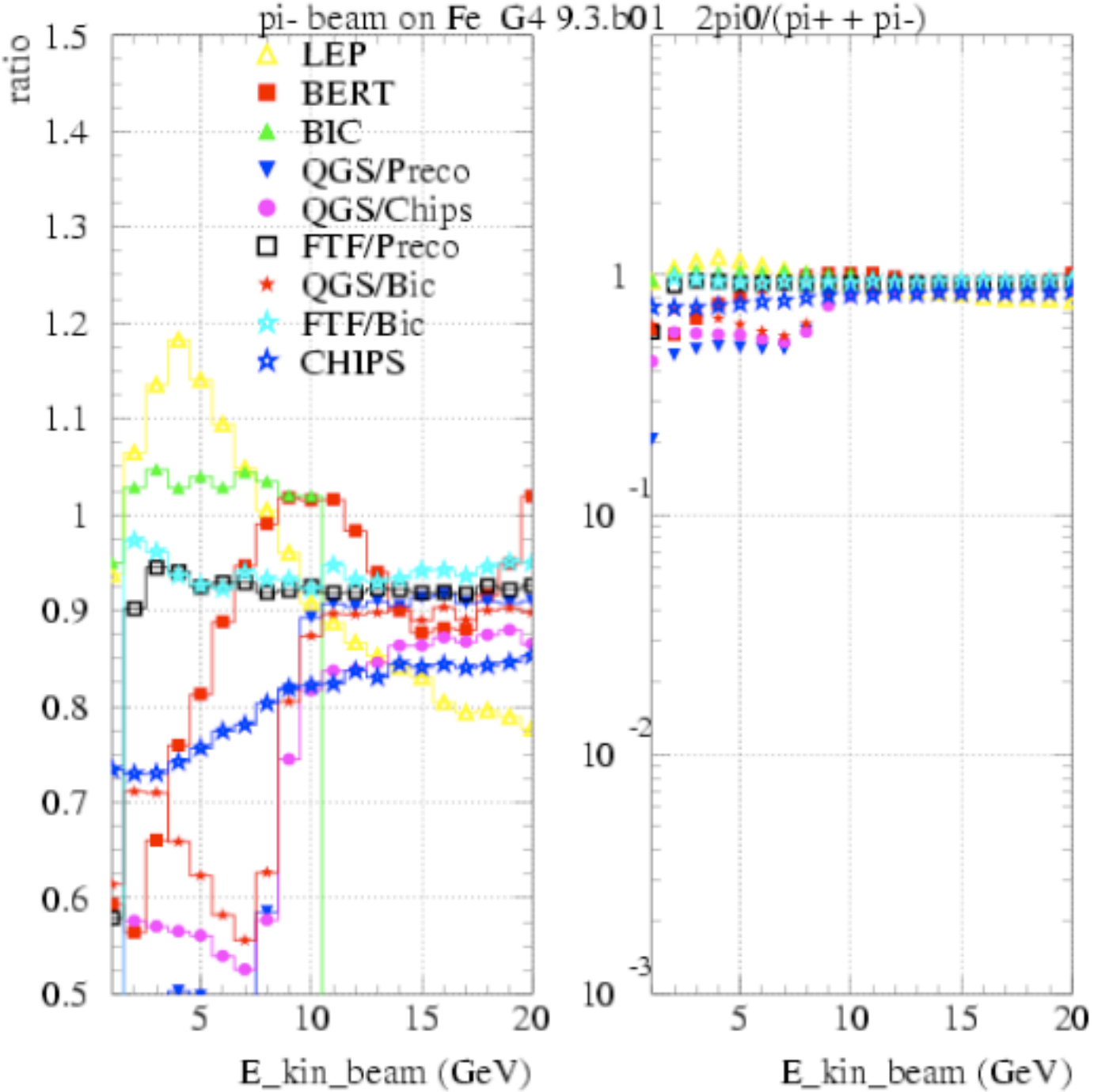
Too much energy into neutrons for Cascade models (BERT, BIC) at all beam energies

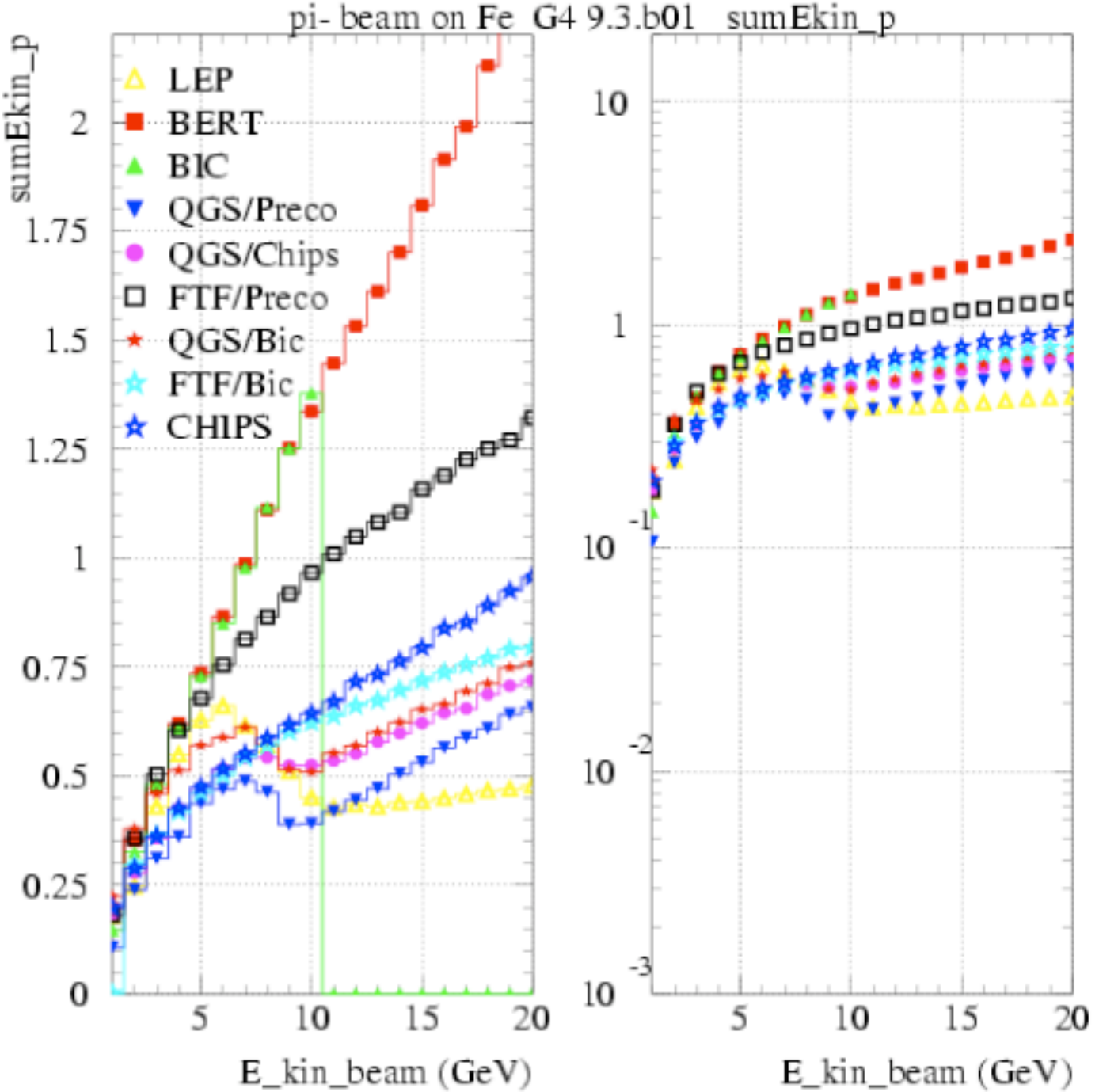


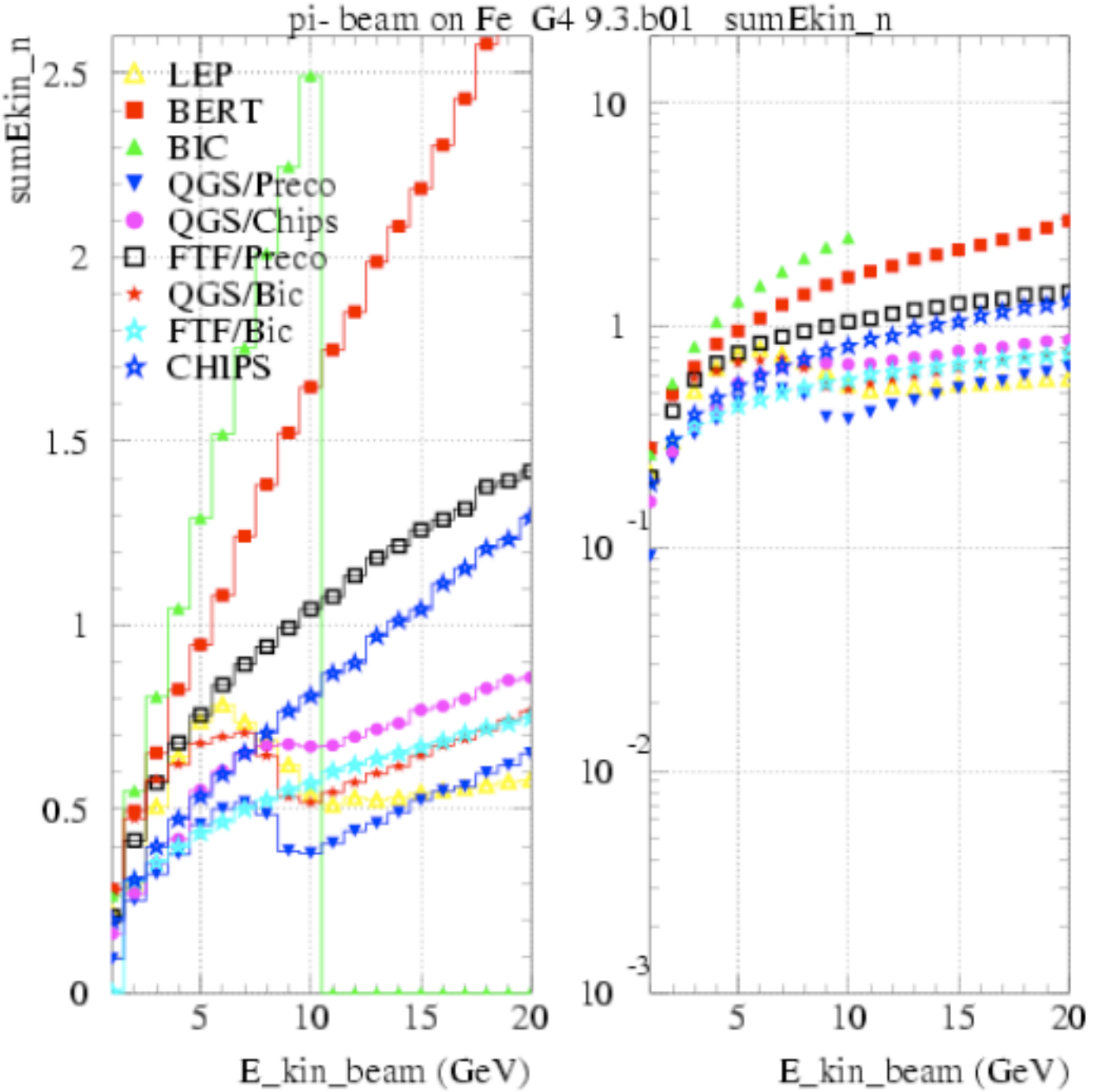

pi- beam on Fe G4 9.3.b01 ion
E_kin/E_tot_beam
E_kin_beam (GeV)
ion LEP
ion BERT
ion BIC
ion QGS/Preco
ion QGS/Chips
ion FTF/Preco
ion QGS/Bic
ion FTF/Bic
ion CHIPS
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
5
10
15
20
10^-1
10^-2
10^-3


pi- beam on Fe G4 9.3.b01 sum/beamEnergy
ratio
1.1
1.075
1.05
1.025
1
0.975
0.95
0.925
0.9
LEP
BERT
BIC
QGS/Preco
QGS/Chips
FTF/Preco
QGS/Bic
FTF/Bic
CHIPS
5
10
15
20
E_kin_beam (GeV)
1
10^-1
10^-2
10^-3
5
10
15
20
E_kin_beam (GeV)


pi- beam on Fe G4 9.3.b01
neutron/proton bkwcms
ratio
E_kin_beam (GeV)
E_kin_beam (GeV)
n/p bkwcms LEP
n/p bkwcms BERT
n/p bkwcms BIC
n/p bkwcms QGS/Preco
n/p bkwcms QGS/Chips
n/p bkwcms FTF/Preco
n/p bkwcms QGS/Bic
n/p bkwcms FTF/Bic
n/p bkwcms CHIPS


pi- beam on Fe G4 9.3.b01 2pi0/(pi+ + pi-)
ratio
LEP
BERT
BIC
QGS/Preco
QGS/Chips
FTF/Preco
QGS/Bic
FTF/Bic
CHIPS
E_kin_beam (GeV)
E_kin_beam (GeV)


pi- beam on Fe G4 9.3.b01 sumEkin_p
sumEkin_p
LEP
BERT
BIC
QGS/Preco
QGS/Chips
FTF/Preco
QGS/Bic
FTF/Bic
CHIPS
E_kin_beam (GeV)
E_kin_beam (GeV)


pi- beam on Fe G4 9.3.b01 sumEkin_n
sumEkin_n
LEP
BERT
BIC
QGS/Preco
QGS/Chips
FTF/Preco
QGS/Bic
FTF/Bic
CHIPS
E_kin_beam (GeV)
E_kin_beam (GeV)

Lessons

- LEP model is quite different from all other models
- Bertini and Binary cascade models appear to produce too much energy in protons and neutrons above around 5 GeV
- Fritiof seems to produce too many π^0 's below 6 GeV
- Quark-Gluon-String model could be extended down to 8 – 9 GeV
- Energy non-conservation to be fixed in FTF/Bic
- RMS are similar for almost all models
- Suggestion on a likely better choice of the transition regions, and/or model mixing (see next slide)

New combination of transition regions or models

- **FTFP_BERT_TRV** : transition between Fritiof (FTF) and Bertini cascade (BERT) moved in the region **6 – 8 GeV** (originally it was 4 – 5 GeV)

- **QGSP_FTFP_BERT** : the idea here is to replace the parameterized model (LEP) with Fritiof/Preco model in a QGSP_BERT-like Physics List. Furthermore, the transition region between FTFP and BERT is **6 – 8 GeV** (instead of 9.5-9.9 GeV)

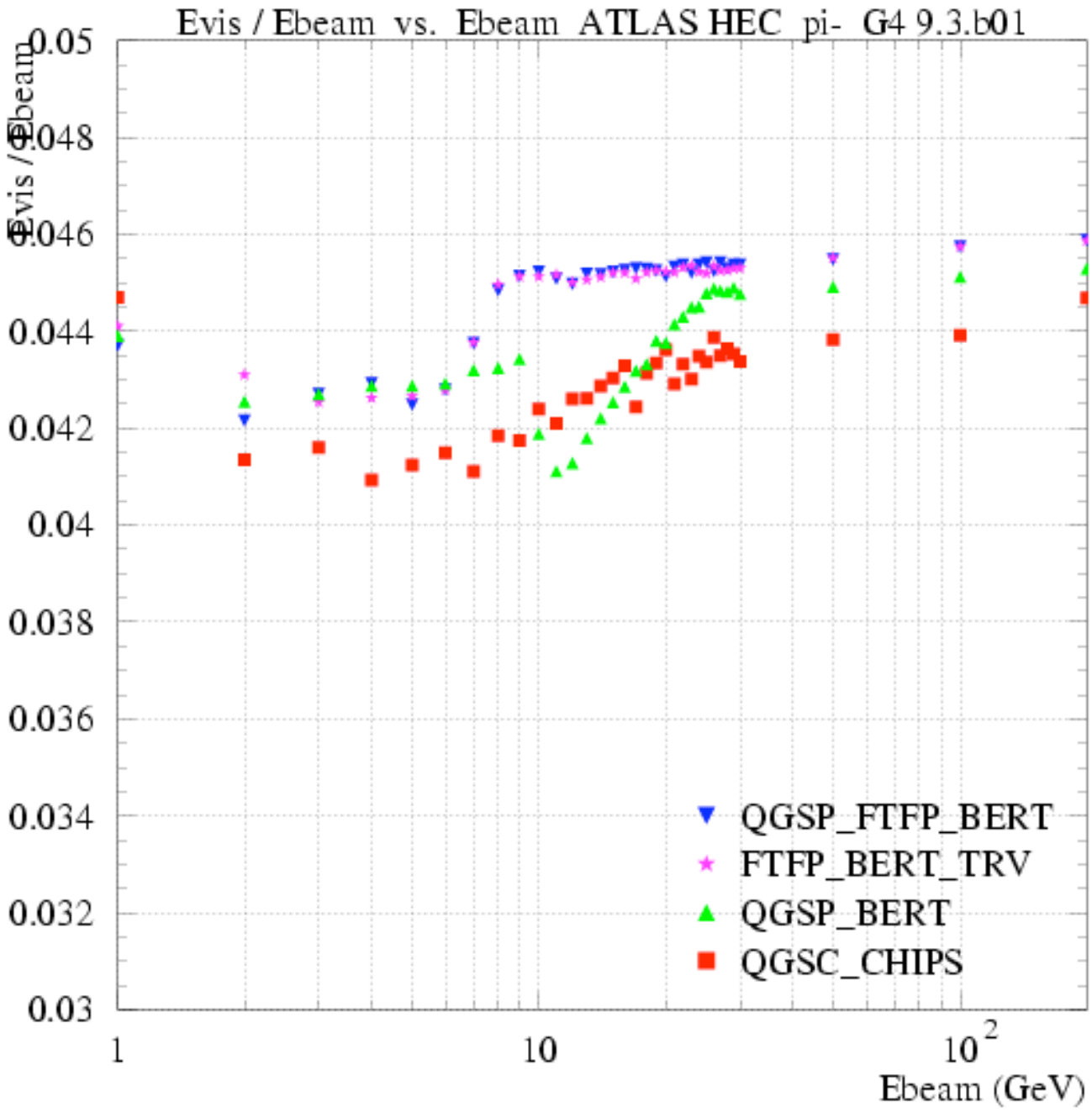
Experimental Physics Lists available in 9.3.b01

Improvements of models

- **BERTini cascade** : improved cross-sections;
  higher multiplicity final-states;
  strange hadron production.

- **Fritiof** : further improved and tuned, based on thin-target data;
  FTF can be now coupled also to a 2-dimensional reggeon cascade + Precompound.

- **CHIPS** : as a model (so without cross-sections) it has been recently extended to all energies (for all hadrons and all materials);
  experimental Physics List QGSC_CHIPS: QGS model with EnergyFlow interface to CHIPS at all energies.


Evis / Ebeam vs. Ebeam ATLAS HEC pi- G4 9.3.b01
Evis / Ebeam
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
1
10
10^2
Ebeam (GeV)
QGSP_FTFP_BERT
FTFP_BERT_TRV
QGSP_BERT
QGSC_CHIPS

Summary & Outlook

- Comparisons between hadronic models provide useful hints on their validity range and it can guide on the choice of the transition regions, or even new mixtures between these models in Physics Lists.

- It is interesting to compare with non-Geant4 models, like Fluka, MCNPX, Dubna cascade, etc.

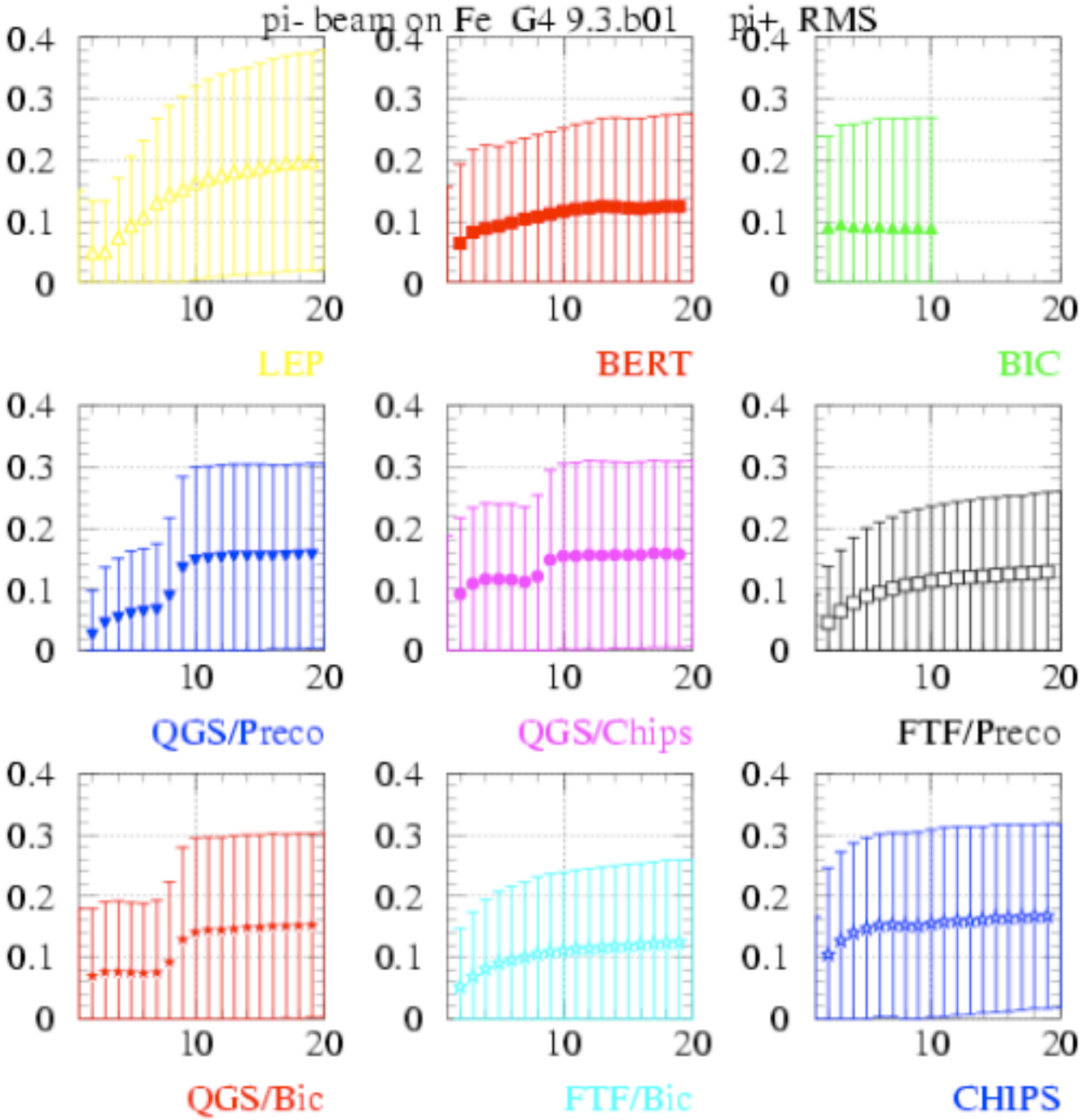
- We should not forget to look at several observables, not only the energy response!

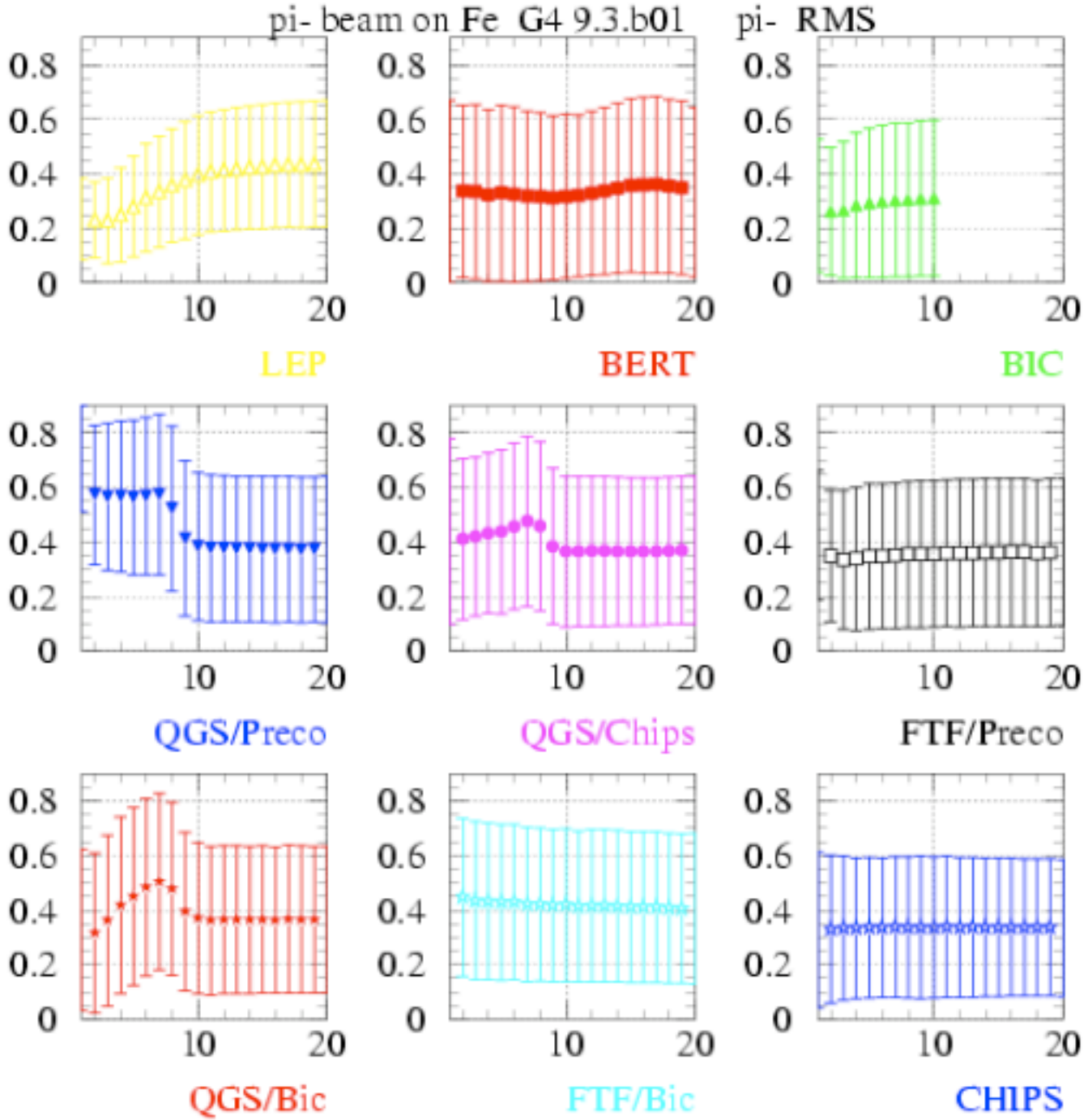
- Work to do:

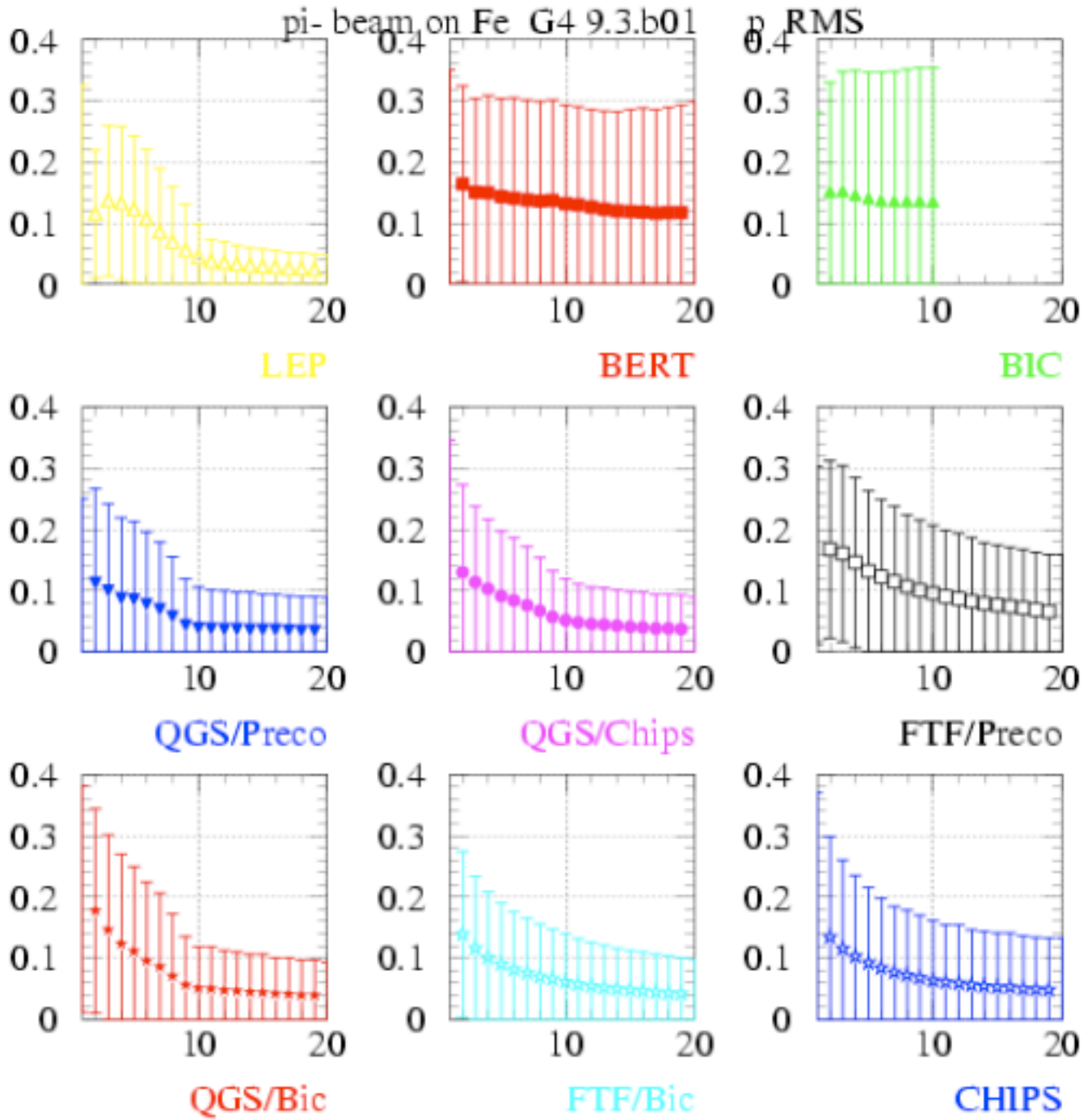
  1) **More validations with thin-target data in 1-20 GeV**
  2) **Continue to improve/extend models**
  3) **Try to link model-level features to calorimeter observables**

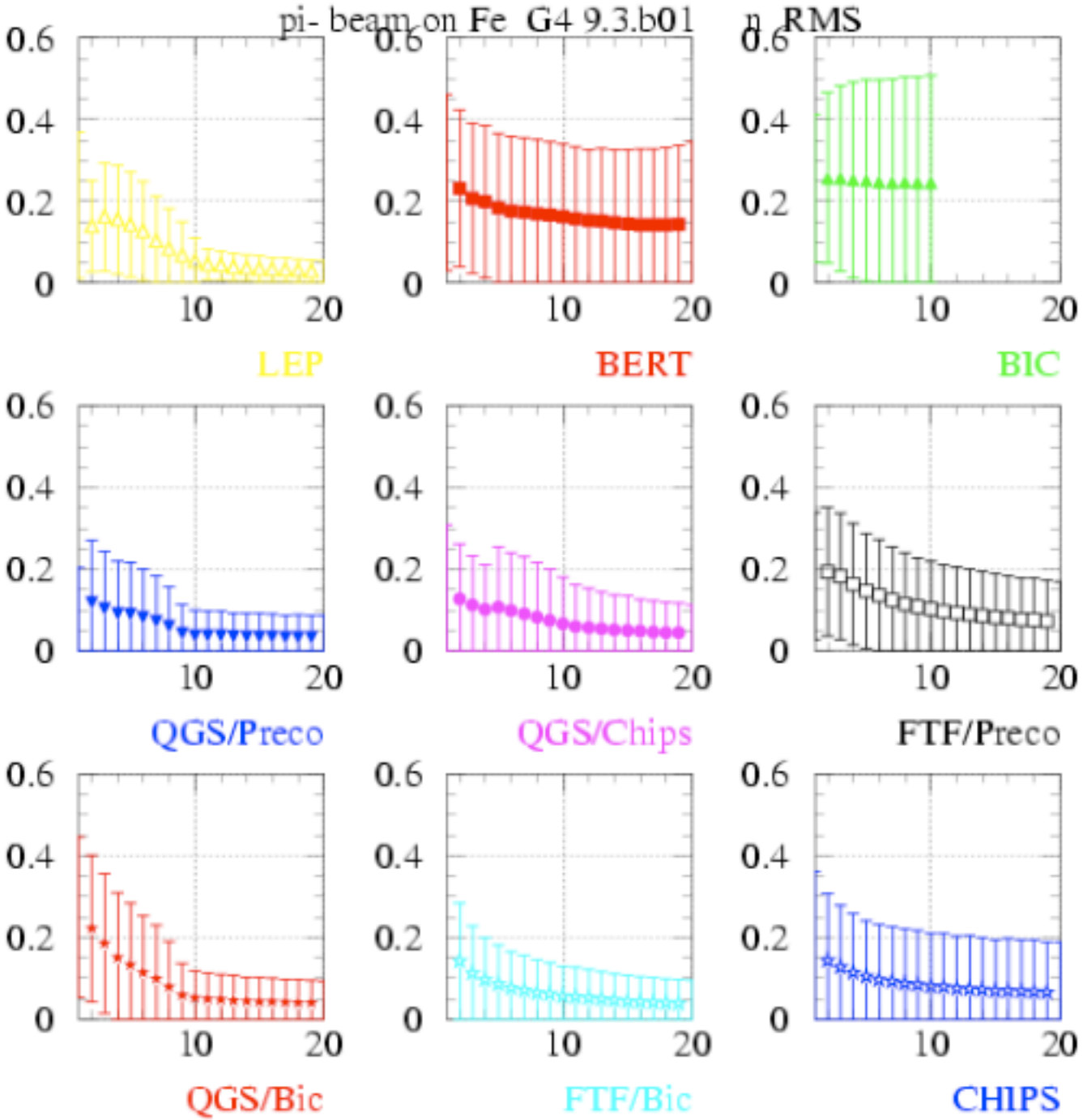
This requires a major effort of all G4 hadronic group!

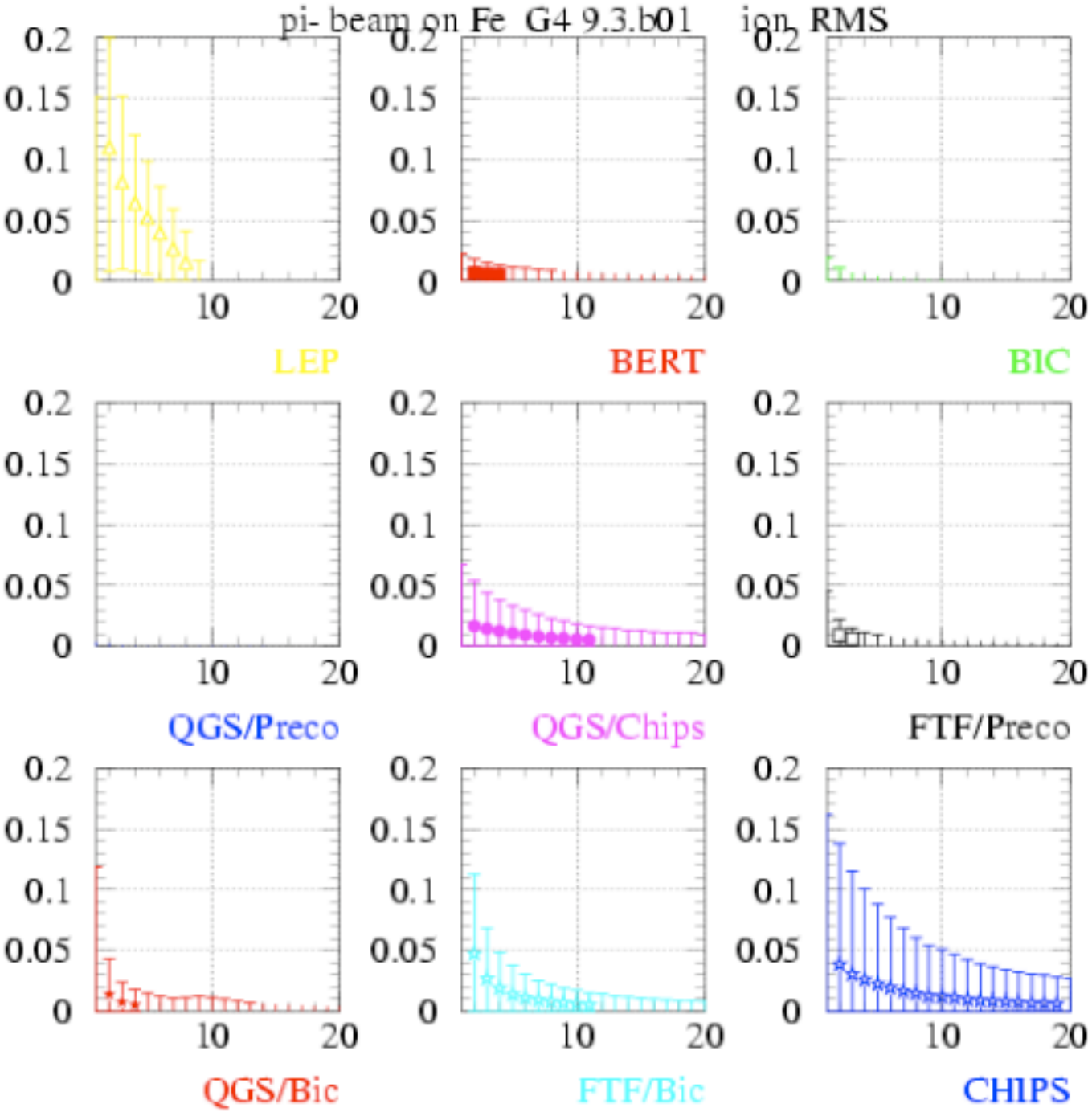
BACKUP SLIDES

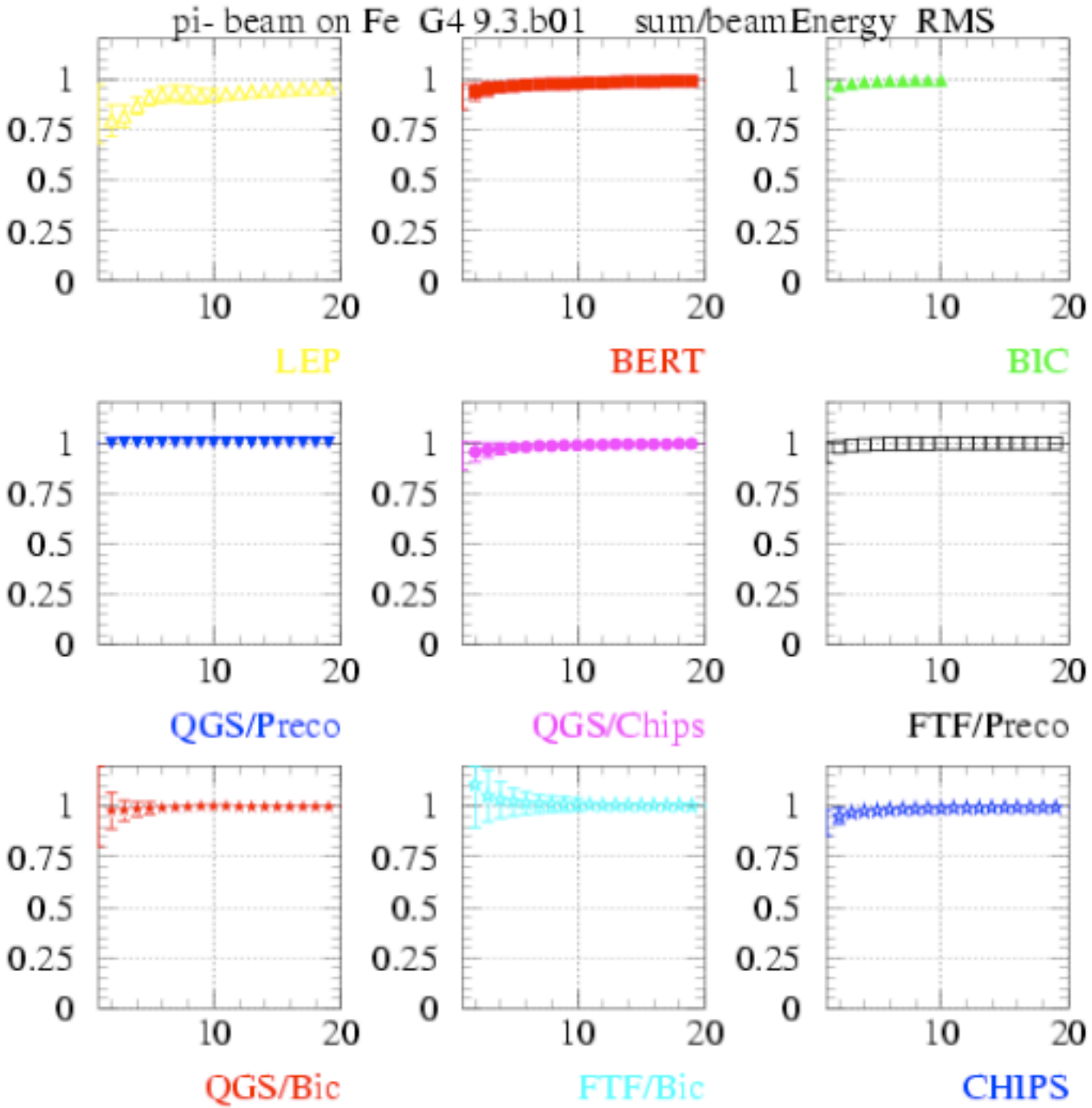

pi- beam on Fe G4 9.3.b01 pi+ RMS
0.4
0.3
0.2
0.1
0
10
20
LEP
BERT
BIC
QGS/Preco
QGS/Chips
FTF/Preco
QGS/Bic
FTF/Bic
CHIPS


pi- beam on Fe G4 9.3.b01
pi- RMS
0.8
0.6
0.4
0.2
0
10
20
LEP
BERT
BIC
QGS/Preco
QGS/Chips
FTF/Preco
QGS/Bic
FTF/Bic
CHIPS


pi- beam on Fe G4 9.3.b01
p RMS
0.4
0.3
0.2
0.1
0
10
20
LEP
BERT
BIC
QGS/Preco
QGS/Chips
FTF/Preco
QGS/Bic
FTF/Bic
CHIPS


pi- beam on Fe G4 9.3.b01 n RMS
0.6
0.4
0.2
0
10
20
LEP
BERT
BIC
QGS/Preco
QGS/Chips
FTF/Preco
QGS/Bic
FTF/Bic
CHIPS


pi- beam on Fe G4 9.3.b01 ion RMS
0.2
0.15
0.1
0.05
0
10
20
LEP
BERT
BIC
QGS/Preco
QGS/Chips
FTF/Preco
QGS/Bic
FTF/Bic
CHIPS


pi- beam on Fe G4 9.3.b01 sum/beamEnergy RMS
1
0.75
0.5
0.25
0
10
20
LEP
BERT
BIC
QGS/Preco
QGS/Chips
FTF/Preco
QGS/Bic
FTF/Bic
CHIPS